

TARGET CHARACTERIZATION AND FOLLOW-UP
OBSERVATIONS IN SUPPORT OF THE KEPLER MISSION

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This is a report on the work carried out under Grant NCC2-1390, "TARGET CHARACTERIZATION AND FOLLOW-UP OBSERVATIONS IN SUPPORT OF THE KEPLER MISSION" during the period 1 October 2002 through 30 September 2003.

A variety of experiments were carried out to investigate the number and characteristics of the stars to be included in the Kepler Input Catalog.

One result of this work was the proposal that the 2MASS Catalog of astrometry and photometry in the infrared be used as the primary source for the initial selection of candidate target stars, because this would naturally decrease the number of unsuitable hot blue stars and would also increase the number of desirable solar-type dwarf stars. Another advantage of the 2MASS catalogue is that the stellar positions have more than adequate astrometric accuracy for the Kepler target selection.

We explored the possibility of using proper motions from the Tycho and USNO-B Catalogs to help separate giants from dwarfs. We discovered that the vast majority of Kepler targets fall in a magnitude range that is not well covered by either catalog. The Tycho 2 Catalog is complete only to 11th magnitude, while the USNO-B Catalog does not kick in until about 15th magnitude, because the brighter stars are saturated on the photographic Schmidt plates that were the source material for this catalog. To address this shortcoming we recruited David Monet, the author of the USNO-B Catalog, to our team. Monet has available to him unpublished scans of short-exposure plates that cover the magnitude range of interest to Kepler. Monet has undertaken the task of producing a catalog of proper motions for the stars of interest in the Kepler Target Region using this plate material. Monet has also started to look at the prospects for using the Kepler observations themselves to derive parallaxes and proper motions.

The original plan reported in the Concept Study Report was to use the parallaxes and multi-band photometry from the FAME mission to provide the information needed for reliable separation of giants and dwarfs. As a result of NASA's withdrawal of support for FAME an alternate approach was needed. In November 2002 we proposed to the Kepler Science Team that a ground-based multi-band photometric survey could help alleviate the loss of the FAME data. The Science Team supported this proposal strongly, and we undertook a survey of possible facilities for such a survey. We concluded that the SAO's 4Shooter CCD camera on the 1.2-m telescope at the Whipple Observatory on Mount Hopkins, Arizona, showed promise for this work. The Kepler Project supported our proposal for a proof-of-concept study to establish the

performance of this facility and to evaluate the feasibility of using it for a survey of the Kepler Target region. We enlisted the collaboration of Tim Brown, Steve Howell, and Mark Everett in this study, and coordinated the preparation and submission of their proposals to carry out the work. This led to a major effort involving 38 nights of telescope time assigned to the study during FY03, work to develop a photometric reduction pipeline, work to develop a database management system for the results, and work to understand the astrophysical analysis of the results. A full report of this effort is scheduled for submission to the Kepler Project by the end of December 2003.

The dependence of the total number of target candidates as a function of the Galactic latitude of the center of the Kepler field was investigated using the 2MASS catalog, and the number of contaminating stars per Kepler image on average was evaluated using the same catalog. The number of false positives due to faint eclipsing binaries contaminating Kepler target images was modelled and published by Tim Brown (2003, ApJ, 593L, 125). On the order of 500 false positives from faint main-sequence eclipsing binaries is expected for a sample of 170,000 Kepler targets.

The Hectochelle multi-fiber spectrograph and all the associated new telescope optics were installed and brought into operation at the MMT. The image performance across the full one-degree field of the MMT is spectacular, with 0.5 arc-second FWHM performance out to the edge of the field. The first observations of Kepler targets with Hectochelle are scheduled for the first week of December 2003. In June 2003 the CfA Digital Speedometers were used to obtain spectra of 151 Tycho 2 stars in 26 fields, each 22 by 22 arc-minutes, spaced at one-degree intervals from Galactic latitude 0 to 25 degrees at Galactic longitude 70 degrees. This work was designed to support the analysis of the number of good Kepler targets in these fields based on 4Shooter images taken of the same fields. These spectra were used to derive effective temperatures, surface gravities, and projected rotational velocities for the 151 stars in the sample.

A prerequisite for effective use of Hectochelle spectra is the extension of SAO's library of synthetic spectra to cover the wider wavelength window of Hectochelle in the Mg b radial-velocity order, 515 to 530 nm. The most demanding part of this work is the preparation of a new line list for the calculation of the synthetic spectra. This work was pursued in an orderly if laborious fashion by Prof. Jon Morse at Arizona State University, with completion of a new fine-tuned list for the wavelength range 506 to 524 nm, a bit more than half the wavelength range required. Work continues on the

remaining wavelength range. Prof. Morse has obtained start-up funding from ASU to hire a postdoc to help with this work. Prof. Bruce Carney, Chairman of the Physics and Astronomy Department at the University of North Carolina in Chapel Hill, has agreed to collaborate with our team on the preparation of a new grid of model atmospheres for the calculation of the new library of synthetic spectra. Most of this work is being carried out at no cost to the Kepler mission.

Substantial work was done to investigate techniques for follow-up observations to confirm transiting planet candidates or identify false positives, and these techniques were applied to transit candidates identified by ground-based photometric transit surveys.

Our follow-up of candidate transiting planets uncovered by the OGLE team has shown that the problem of false positives is of crucial importance for the confirmation of any detection. To address this issue in the context of the follow-up of a sample of faint OGLE candidates toward the bulge of the Galaxy, a number of tests were applied or developed to improve the chances of finding a true planet. These included:

- 1) Careful examination of the morphology of the light curves for signs that the companion is stellar, such as curvature outside of eclipse due to gravity darkening or heating effects (Drake 2003; Sirko & Paczynski 2003), or hints of a secondary eclipse.
- 2) Low resolution spectroscopic observations to provide spectral types and coarse radial velocities. This allowed a large fraction of the initial candidates to be rejected as being due to large primaries (early-type stars) or stellar companions (which produce large and easily measurable reflex motions on the stars).
- 3) High resolution observations of the remaining objects to attempt to detect the reflex motion of the orbiting body and determine its mass. These observations were examined carefully for signs of stellar companions in two ways (Konacki et al. 2003b): a) by direct inspection of the spectra with TODCOR (a two-dimensional cross-correlation technique) to place upper limits on the brightness of any additional star, and b) by computing the spectral line bisectors to check for asymmetries that correlate with the photometric phase, which would indicate a blend.
- 4) Blend simulations in which fits to the OGLE light curves were carried out by adopting a model in which an eclipsing binary has its normal deep eclipses diluted by the light of a third star along the same line of sight. Full-blown eclipsing binary light curve solution

codes were used, and the radiative and geometric properties of the stars were adopted from model isochrones. Different isochrones were adopted for the binary and the third star if a chance alignment, or else the same isochrone was adopted if the system is a physical triple. A full description of this tool is in preparation (Torres et al. 2004), with an application to OGLE-TR-33, a blend case which also shows variable line asymmetries.

Only one of the remaining OGLE candidates in the bulge passed these tests and yielded a positive detection of a small reflex motion due to a planet: OGLE-TR-56. It was announced as the second known extrasolar transiting planet (after HD 209458) earlier this year (Konacki et al. 2003a), and the radial velocity changes were recently confirmed with additional measurements (Torres et al. 2003c).

An important result of the reconnaissance described above is that up to 98% of the original OGLE candidates in the bulge are false positives. The low yield may be partly due in this case to the crowded field toward the Galactic center, but it emphasizes the importance of careful screening of any candidates before they can be claimed to be true planets.

Some of these results were documented in papers that were published or submitted during the reporting period:

Konacki, M., Torres, G., Jha, S., & Sasselov, D. D. 2003a, *Nature*, 421, 507

Konacki, M., Torres, G., Sasselov, D. D., & Jha, S. 2003b, *ApJ*, in press (astro-ph/0306542)

Torres, G., Konacki, M., Sasselov, D. D., & Jha, S. 2003c, *ApJL*, submitted (astro-ph/0310114)

John Geary participated in 5 Monthly management Review meetings in the reporting period. During each of these, there were breakout meetings to address aspects of the signal processing scheme, detector testing, and radiation hardness issues. Funds to support Geary's travel for these meetings had been removed from our proposal in response to a request from the Kepler Project to reduce our costs. However, problems arose in funding his travel through Ames, so we ended up covering some of these costs.

Latham participated in the November 2002 Science Team meeting, staffed the Kepler booth at the AAS meeting in January, organized a special meeting at Ames to discuss possible ground-based photometric surveys

in January, participated in the Ground Segment Working Group meetings in March and June, the Eddington Workshop in Palermo in April, a James Webb Space Telescope workshop on Astrobiology in May (where he presented the case for follow-up observations of Kepler targets with JWST), and 4Shooter observing in December, May, June, July, and September. Monet participated in the Ground Segment Working Group meeting in June.

Latham participated in many telcons, including most of the Ground Segment Monthly management reviews, many of the weekly Ground Segment Working Group discussions, the Systems Requirement Review planning discussions and flip-through, and the Ground Segment Requirements Document walk-through.

Latham presented two colloquia (Pittsburgh and Caltech) and three public talks that featured the Kepler mission.